UNCLASSIFIED Unlimited Distribution

FRACTURE OF TEMPER EMBRITTLED HY130 WELDMENTS

J. Morrison

February 1984

For

Defence Research Establishment Pacific
Centre de recherches pour la defense pacifique

TECHNICAL MEMO 84-1

DEFENCE RESEARCH ESTABLISHMENT PACIFIC

CFB Esquimalt, FMO Victoria, B.C. VOS 1BO

FRACTURE OF TEMPER EMBRITTLED HY130 WELDMENTS

by

J. Morrison

February 1984

Approved by:

CHIEF

Research and Development Branch
Department of National Defence

Canada

Abstract

This report describes an investigation of the embrittlement associated with thermal stress relief of multipass butt welds in 13-mm and 25-mm HY130 plate. While the parent metal is not greatly affected by a stress relief treatment, shielded metal-arc weldments suffer a drastic drop in Charpy V-notch toughness when slow cooled from the tempering temperature. Instrumented impact tests suggest that while both crack initiation and propagation resistance are lowered by slow cooling after tempering, the energy associated with propagation is more severely affected. J_I-R curve measurements tend to support these observations; the crack initiation toughness remains relatively high and the embrittlement is characterized by a loss of tolerance for propagating cracks.

INTRODUCTION

The residual stresses which are unavoidably introduced during fabrication are occasionally beneficial, but more often they limit performance by accelerating failure from fatigue, brittle fracture, stress corrosion cracking, or dimensional instability. In particular, weldments inherently possess extremely high localized residual stresses and are especially susceptible to these types of problem.

Since the mid-1970's, the Canadian Department of National Defence has funded a number of investigations of the engineering properties of HY130 steel and its weldments. Of particular interest was the assessment of post-weld residual stresses, their effect on mechanical behaviour, and the effectiveness of various types of stress relief treatment.[1]

In general, the residual stresses were found to be high, approaching yield strength magnitude close to or inside the weld.[2,3] Comparisons were made between vibratory and thermal stress relief techniques, the latter being found to be by far the more effective. Unfortunately, such thermal stress relief treatments are not recommended for HY130 weldments because of the risk of encountering temper embrittlement[4], whereby heating or slow cooling in the range 350-550°C results in an increase in ductile-brittle transition temperature and a tendency to intergranular brittle fracture along prior austenite grain boundaries. It has been demonstrated that specific impurities (for example, Sb, As, Sn, P) are responsible for the embrittlement by means of reversible segregation, though the effect of alloy content varies considerably among different classes of steels, and the actual segregation mechanisms are still relatively poorly understood.[5]

This paper will focus on the response of shielded metal-arc HY130 weldments to thermal stress relief treatments, including the effect of temperature, time, and cooling rate. The test procedures used include standard Charpy V-notch impact tests, instrumented Charpy, and J_I-R curve measurements.

WELDING PROCEDURE

Table I shows the measured chemical compositions and mechanical properties of the as-received 13- and 25-mm air-melt vacuum-degassed HY130 plates. Also shown for comparison are the specified values for HY130.[6] The welds were all longitudinal shielded metal-arc double 'V' butt welds using MacKay E14018 4 mm diameter electrodes. They were centrally located along the length of the 250 by 500 mm rectangular sections. Welding parameters were in accordance with recommended procedures[7] using a multipass stringer technique with 6-8 passes in 13-mm thick samples, and 12-16 passes in 25-mm thick samples, at a travel speed of 150-250 mm/min. The electrodes were baked at 460°C for 2 h, then held at 150°C and used within 20 min of removal from the oven. Preheat and interpass temperatures were maintained within the range 90-135°C, and the plates were held at 150°C for 24 h after welding and then radiographically inspected to ensure freedom from defects.

Typical weldment mechanical properties are also shown in Table I. The weldments were in general comparable to parent metal and to the manufacturer's specification for weld metal, any reduction in yield strength being reflected in higher ductility.

The as-supplied HY130 plates had been austenitized at 830°C then tempered at 650°C and water quenched. Temper embrittlement may result from slow cooling in the temperature range 350 - 550°C. For the purposes of this study, therefore, data are presented for three stress relief treatments in order to provide an indication of the effect of time and temperature on the degree of embrittlement. The treatments were 2 and 24 h at 540°C, and 2 h at 600°C (the 13-mm samples were exclusively treated at 540°C). In most cases furnace cooled specimens have been compared to air cooled, as well as to non-stress relieved specimens. Except where indicated, all specimens were oriented T-L, so that the crack propagation direction is parallel to the long axis of the weld stringer beads, and all notches were located as closely as possible to the weld centre line.

TABLE I

CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES

a) Chemical Composition Weight %

Material		C	Mn	P	S	Si	Ni	Cr	Mo	V	Cu	Ti
HY130 Specified	min.	-	.55	-	-	.13	4.68	.36	.27	.04		
	max.	.12	.95	.012	.012	.37	5.32.	.74	.68	.11	.25	.02
HY130 As-received	12 mm	.10	.70	.005	.007	.23	4.90	.54	.49	.08	.05	.008
	25 mm	.10	.80	.008	.003	.32	4.95	.54	.50	.07	.05	.003
E14018		-	.90	-	.005	-	3.50	.55	.64	-	-	-

b) Tensile Properties

Material		0.2% Proof-Stress (MPa)	UTS (MPa)	Elongation %	R.A. %
HY130 Specified	transverse	900-1000	-	15	50
HY130 As-received	12 mm	980	1030	27	55
	25 mm	980	1025	19	-
E14018	manufacturer's values	970	1010	18	-
As Welded	longitudinal	937	1116	29	39
	transverse	806	1027	44	58

STANDARD CHARPY IMPACT TESTS

Table II shows the effect of various stress relief treatments on the Charpy V-notch (10 mm by 10 mm specimens) impact energy at 0°C for both 13-mm parent metal and weldment. In can be seen that both had good impact toughness in the non-stress relieved condition. The parent metal itself did suffer some appreciable loss in toughness when furnace cooled after sufficient time at 540°C. In the case of the weldment, however, there was a dramatic deterioration in properties after the same treatment. The effect of cooling rate is also clearly seen.

Similar data for 25-mm samples tested at -20°C is shown in Table III. Again the non-stress-relieved parent metal and weldment both had excellent toughness. The HY130 plate is more or less immune to short time temper embrittlement. In fact, as shown in Figure 1, furnace cooling

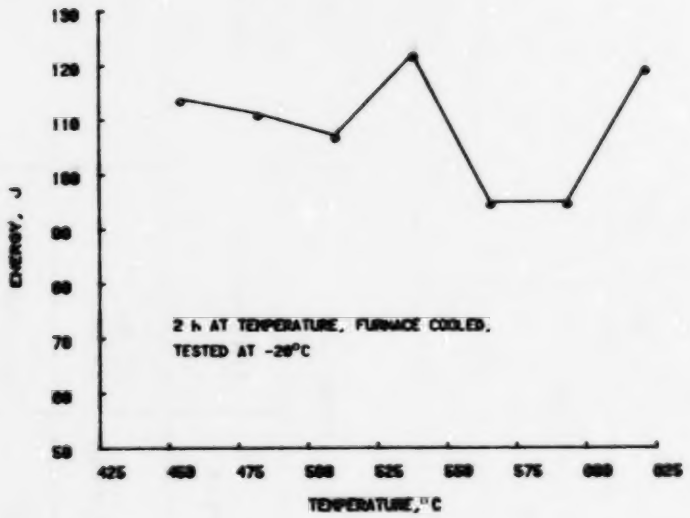


Figure 1. Average CVN results for 25-mm parent metal.

TABLE II

CVN ENERGY (JOULES) AT 0°C - 13 mm PLATE

Condition		Parent Metal	E14018 Weldment
Non-stress-relieved		94	68
2 h at 540°C	FC	75	38
	AC	-	50
	WQ	-	55
24 h at 540°C	FC	-	14
	AC	-	36

TABLE III

CVN ENERGY (JOULES) AT -20°C - 25 mm PLATE

Condition		Parent Metal	E14018 Weldment
Non-stress-relieved		111	88
2 h at 540°C	FC	120	65
2 h at 600°C	FC	94	58
	AC	114	110
2 h at 600°C	FC	119	20

TABLE IV

INSTRUMENTED CHARPY ENERGIES (JOULES) AT 0°C - 13 mm PARENT METAL

Condition		E_i	E_p	E_{total}
Non-stress-relieved		30	64	94
24 h at 540°C	FC	20	18	38
	AC	26	30	56

TABLE V

INSTRUMENTED CHARPY ENERGIES (JOULES) AT 0°C - 13 mm WELDMENT

Condition		E_i	E_p	E_{total}
Non-stress-relieved		24	47	71
2 h at 540°C	FC	11	24	35
24 h at 540°C	FC	4	15	19

after a 2 h treatment within the entire 450 - 625°C temperature range did not lead to significant decrease in impact energy. In contrast, Table III shows that, corresponding to results on 13-mm material, 25-mm weldments suffer drastic embrittlement on furnace cooling after sufficient time at 600°C. Such is the inherent scatter in weldment impact properties that individual readings were as low as 5 Joules. The transition curves (average values) for both air cooled and furnace cooled samples are shown in Figure 2.

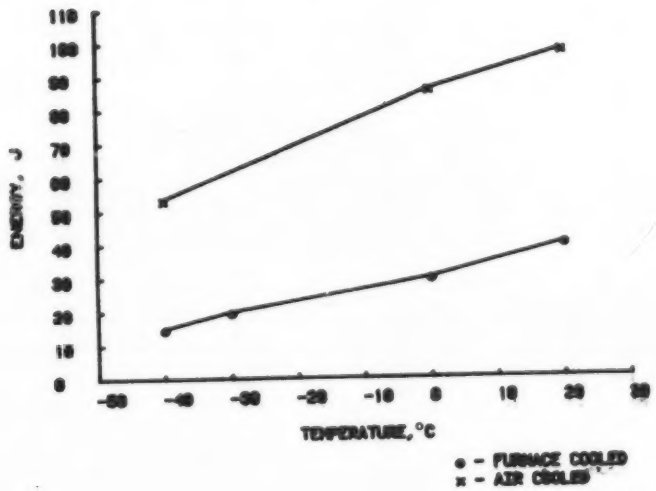
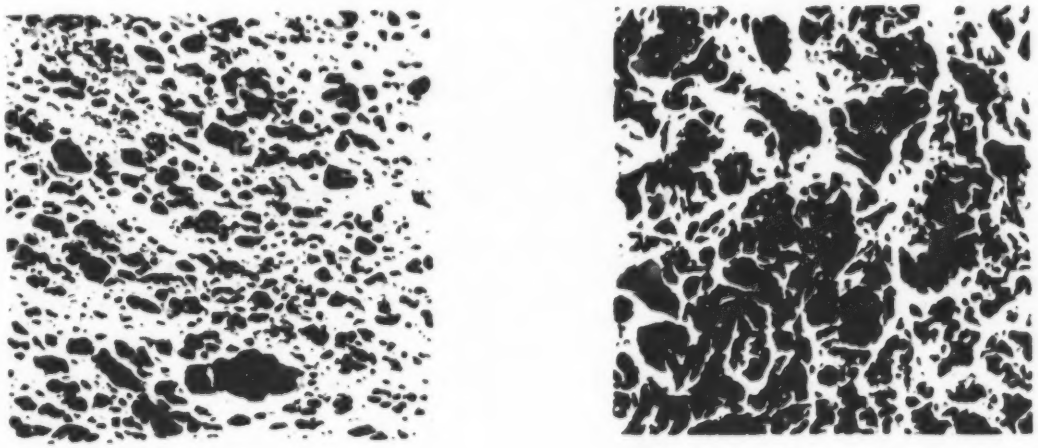


Figure 2. CVN transition curve for 25-mm weldments.

Table III also indicates that air cooling from 600°C resulted in de-embrittlement and often gave better properties than in the non-stress-relieved condition. This is in contrast to the 540°C treatment, where even water quenching would not fully restore the as-welded toughness. Complete de-embrittlement is achieved after only a few minutes at temperatures above 600°C followed by water quenching.

Examination of the fracture surfaces of the 13-mm weldment specimens tested as 0°C showed that in as-welded samples fracture occurred by a ductile microvoid coalescence type mechanism (Figure 3) and was accompanied by extensive shear lip formation. In embrittled samples, on the other hand, fracture was characterized by extensive brittle intergranular separation. Even in this case, a narrow band showing microductility was apparent beneath the machined notch, and there were indications that the extent of embrittlement was reflected in the depth of this ductile zone.



(a) As-welded. (b) Tempered 24 h at 540°C FC.

Figure 3. Scanning electron micrographs of weld fracture surfaces from broken Charpy specimens tested at 0°C. (X 1000)

INSTRUMENTED IMPACT TESTS

To distinguish between crack initiation and crack propagation energies, instrumented impact tests were conducted on 13-mm material to provide an oscilloscope trace of load versus time. The total energy required to fracture the specimen was separated into pre- and post-maximum load components (E_i and E_p), which were assumed to be associated with crack initiation and propagation respectively. Implicit in this approach is the assumption that the crack initiation event occurs at peak load. Table IV shows the results for HY130 parent material, and indicates that the loss in impact toughness as a result of the 540°C treatment is accompanied by a greater drop in E_p relative to E_i. In the case of the SMA weldment, although in absolute terms the drop in E_p is larger, meaningful quantitative data is difficult to obtain because of the very low energies

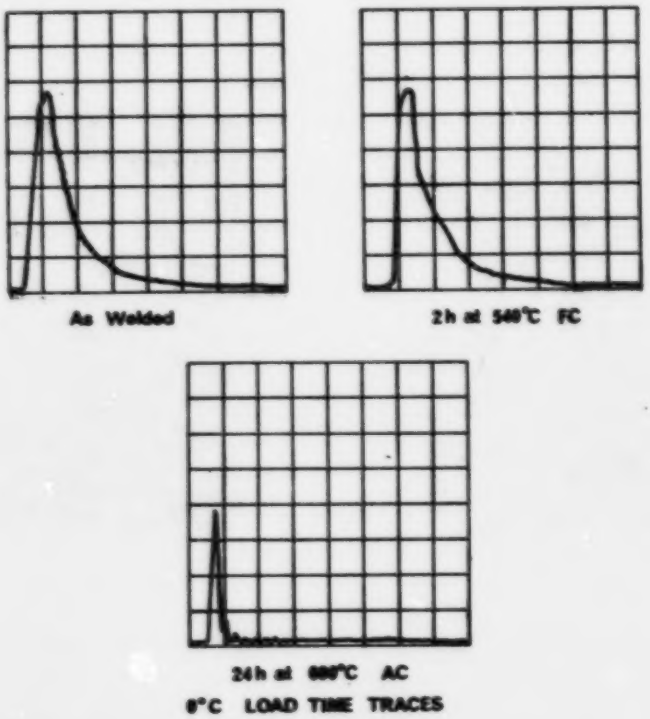


Figure 4. Load-time traces from instrumented impact tests at 0°C.

measured for embrittled weldment (Table V). However, as shown in Figure 4, there are qualitative indications that after 2 h at 540°C, the drop in total energy is entirely the result of a drop in area under the curve following peak load (E_p). The behaviour up to peak load is still primarily ductile and qualitatively similar to that of the as-welded samples. Only after much longer time at temperature does the characteristic ductile behaviour disappear, and the peak height begin to drop.

These results suggest that a K_{Ic} or J_{Ic} type measurement of crack initiation resistance would not be greatly affected by short time treatments, although the character and slope of the J_I-R curve would be reduced as crack propagation resistance decreased. The longer time and/or higher temperature treatment would result in a lower initiation toughness in furnace cooled specimens, and fracture instability at peak load.

Measurements were made by dynamic J_{Ic} using precracked side-grooved Charpy specimens in a drop-weight instrumented impact machine. J was calculated on the basis of energy to maximum load.[8] The average room temperature K_{IJ} toughness for as-received parent HY130 13-mm plate was 178 MPa$\sqrt{m}$. Unfortunately a large scatter was obtained in the results from welded samples, so that no consistent trends were established resulting from the different embrittling stress relief heat treatments. The global average obtained was 134 MPa$\sqrt{m}$. Samples air-cooled after tempering at 600°C gave consistently higher values than the as-welded material, with an average K_{IJ} of 163 MPa$\sqrt{m}$.

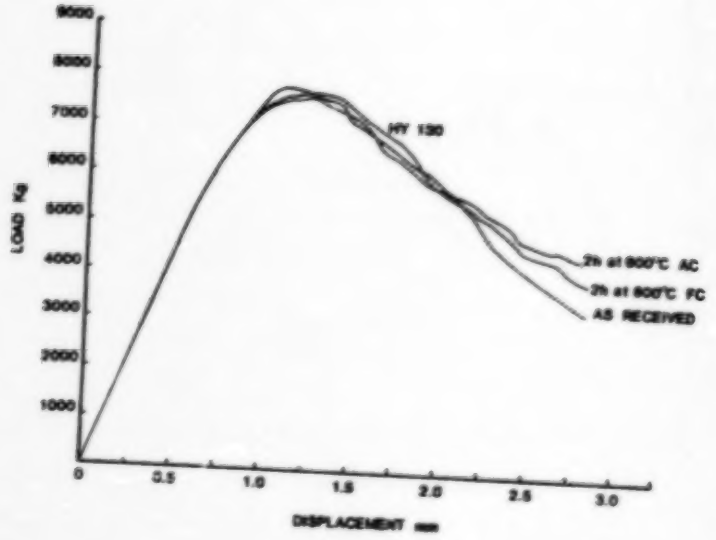
J_I-R CURVE DETERMINATION

To characterize the slow stable crack growth resistance, quasi-static J_I-R curve tests were conducted on full thickness 25-mm 1T compact specimens at room temperature. After fatigue precracking, all specimens were side-grooved ten percent of the thickness to maintain crack front straightness during the slow crack extension. A servo-hydraulic testing machine was used for manual partial unloading compliance tests in accor-

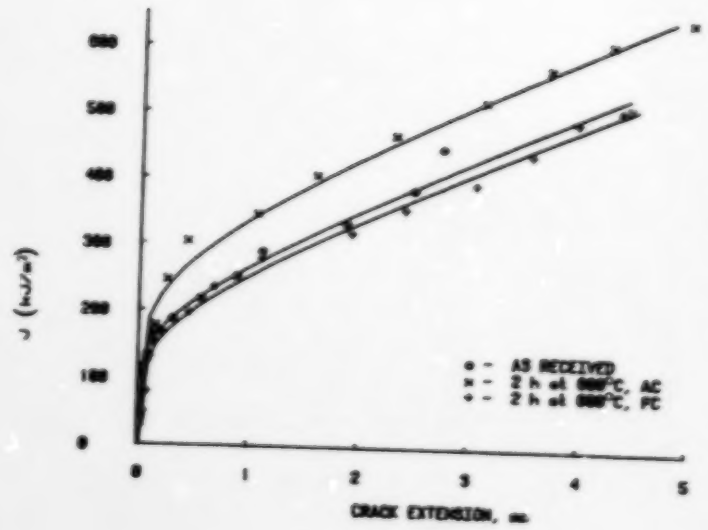
dance with the tentative test procedure recently developed by an ASTM Working Group.[9] At regular intervals of load line deflection (chosen so as to give reasonably spaced data points on the resistance curve) crack length is estimated from the specimen stiffness determined during a partial unloading sequence. A combination of X-Y recorders was used to provide plots of load versus crack mouth opening, one of which was sufficiently magnified to provide an accurate compliance estimation during the repeated unloadings. The test was stopped when either unstable crack extension was encountered or when specimen compliance indicated approximately 5 mm of crack growth, after which the final crack length was marked by heat tinting, and the specimen broken open.

Figure 5 shows the load-displacement curves (uncorrected for small differences in initial crack length and with the partial unloadings removed) for parent plate specimens together with the corresponding J_I-R curves. J was calculated using a crack growth corrected expression[10], and displacement measured between knife edges located on the load line. It can be seen that these specimens sustained a full range of stable tearing and that, in agreement with the Charpy data, there is no effect of either furnace or air cooling following a 600°C temper.

Figure 6 shows the corresponding curves for welded specimens. The as-welded material shows an extensive range of stable crack growth. In addition, these samples sometimes produce a small characteristic 'pop-in' during the initial linear loading. It was assumed that this was associated with minor straightening at the tip of the fatigue crack. Both crack initiation toughness and resistance to stable tearing are somewhat lower in welded samples than in parent metal. No major change is evident in furnace cooled specimens after 2 h at 540°C; merely a small reduction in the R-curve. In contrast specimens furnace cooled after 24 h at 540°C or 2 h at 600°C show unstable brittle fracture at maximum load, with sudden crack advances of several mm being observed. The de-embrittlement effect of air cooling from 600°C is evident in the improved toughness and raised R-curve.

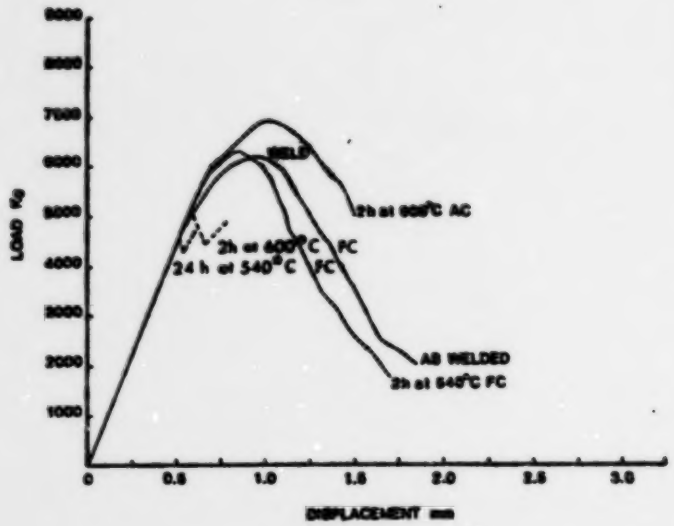


(a) Load-displacement curves.

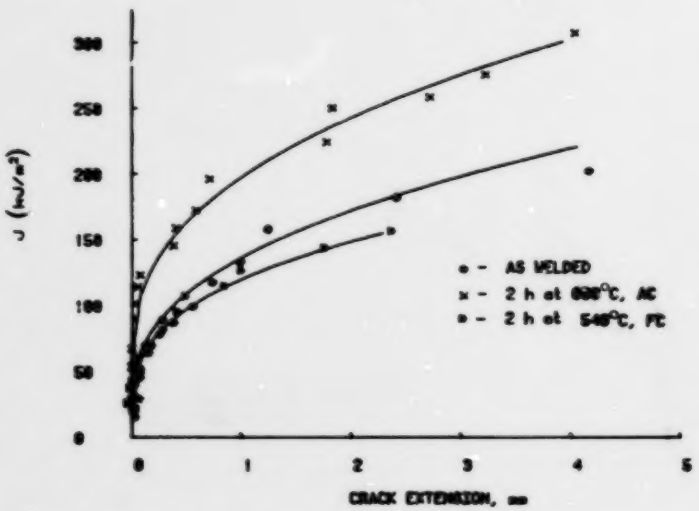


(b) J_I-R curves.

Figure 5. Unloading compliance test results for 25-mm parent plate.



(a) Load-displacement curves.



(b) J_I-R curves.

Figure 6. Unloading compliance test results for weldments.

To provide a quantitative comparison of crack initiation toughness, three different stress intensities have been calculated from these curves and are shown in Table VI. From the load deflection curves, K_Q is an invalid toughness based on a five percent change in specimen compliance as per ASTM Standard E399, and K_{MAX} is the corresponding value based on maximum load. The third parameter K_{IJ} corresponds to a J_{Ic} taken from the J_I-R curves using a linear extrapolation from 1.5 mm of crack extension to the blunting line, in accordance with ASTM Standard E813, using the expression:

$$K_{IJ} = \left(\frac{J_{Ic} \, E}{1 - \nu^2} \right)^{\frac{1}{2}} \tag{1}$$

where E is Young's Modulus and ν is Poisson's ratio (taken as 0.3). Also shown in Table VI are the dimensionless tearing modulus values T, where:

$$T = \frac{dJ}{da} \cdot \frac{E}{\sigma_0^2} \tag{2}$$

dJ/da was obtained from a simple linear extrapolation of the curves in Figures 5 and 6 and σ_0 is the mean of yield and ultimate stresses. The T values provide a rough comparison of stable crack growth resistance. In the case of embrittled samples, there was no region of extensive ductile tearing, and consequently no elastic-plastic R-curve, so that in these cases only a K_Q or K_{MAX} could be measured.

Table VI indicates that in the 25-mm parent material, there is reasonable correlation between K_{MAX} and K_{IJ}, with values in the range 180 - 200 MPa$\sqrt{m}$ in good agreement with the 178 MPa$\sqrt{m}$ average from the dynamic tests on the 13-mm plate. The K_Q values average about 25 - 30% less. The K_{IJ} - K_{MAX} correlation is in agreement with previous work where J_{Ic} was determined to occur in the vicinity of maximum load.[11] Table VI also confirms the insensitivity of the parent 25-mm plate to thermal stress relief treatments.

TABLE VI

ELASTIC PLASTIC J_I-R CURVE RESULTS - 25 mm T-L COMPACT SPECIMENS

Condition		K_Q	K_{MAX} (MPa $\sqrt{m}$)	K_{IJ}	T
A Parent Plate					
non-stress-relieved		140	196	184	23
2 h at 600°C	FC	139	193	234	23
	AC	142	189	186	25
B Weldment					
non-stress-relieved		112	160	118	11
2 h at 540°C	FC	131	153	116	9
24 h at 540°C	FC	-	110	-	-
2 h at 600°C	FC	-	108	-	-
	AC	118	172	145	12

The K_{IJ} - K_{MAX} agreement is also found in the case of weld metal air cooled from 600°C, which has significantly greater resistance to crack initiation than the as-welded condition. The as-welded and 2 h at 540°C specimens show better correlation of K_Q with K_{IJ}, giving values in the range 110 - 120 MPa $\sqrt{m}$ (60 percent of parent metal toughness), although there is greater data scatter in weldment sample data relative to parent metal. There is a rough correlation of tearing modulus with toughness in these specimens, with values of about half those for parent plate.

Embrittled samples have crack initiation toughnesses (which are close to valid K_{IJ} values) only a few percent below K_{IJ} for non-treated specimens.

DISCUSSION

The J_{Ic} results for the 25-mm HY130 plate are in good agreement with the value of 150 kJ/m^2 reported elsewhere for material of the same thickness.[12] The limited data for 13-mm plate from instrumented precracked Charpy tests showed a similar average value. The T data are also close to the value of 26 reported in reference 12 for non-side-grooved specimens, although this value was more than halved when the specimens were 20 percent side grooved.

The temper embrittled weldments cannot be tested so as to provide a valid K_{IJ} in accordance with ASTM E399, since the minimum thickness requirement at a toughness of 110 MPa$\sqrt{m}$ would be more than 30 mm. Clearly a J_{Ic} type test is impossible because of the absence of stable crack growth. The best estimate of crack initiation resistance is thus the K_{MAX} value based on P_{MAX}.

Test data from both instrumented impact and elastic-plastic fracture tests indicate a decrease primarily in crack propagation resistance resulting from slow cooling of weldment samples following a stress relief temper. These observations are supported by the metallographic evidence that in such samples fracture occurs by brittle intergranular separation following crack initiation involving significant microductility.

In a linear-elastic analysis, the critical Mode I stress intensity defining critical combinations of elastic fracture stress σ, and crack size a, for different materials can be compared using an expression of the form:

$$K_{IJ} = Y\sigma\sqrt{\pi a} \qquad (3)$$

where Y is a geometrical term for a particular component or structure. Assuming Y is equal to unity and taking σ as an operating stress equal to half the yield stress, the critical crack size predicted by equation (3) for HY130 would be about 43 mm.

The corresponding value for as-welded material would be 18 mm, compared with 15 mm for the embrittled weldment using K_{MAX}. These flaw sizes do not in practice represent a true failure condition under most conditions for the parent and as-welded material, since large amounts of subcritical tearing can be anticipated. Nevertheless the small difference predicted for the two weldment conditions provides no indication of the drastic loss of crack growth resistance in the embrittled sample. Nor does it provide any indication of the much greater risk of catastrophic damage in this crack intolerant material, particularly since fatigue crack growth rates are known to be significantly higher in stress relieved weldments. There is a continuing requirement for a variety of crack initiation and propagation tests to ensure satisfactory performance in the presence of defects in welded structures.

CONCLUSIONS

a. Shielded metal-arc weldments of HY130 plate using E14018 electrodes are susceptible to embrittlement when slowly cooled after a stress relief temper. The embrittlement is characterized by a large drop in Charpy impact energy which can be restored by a de-embrittlement temper above 600°C followed by more rapid cooling.

b. There is a change in Charpy fracture appearance as a result of temper embrittlement, from a ductile microvoid coalescence appearance to a predominately brittle intergranular failure, though a small region of ductile rupture is usually also found immediately below the notch tip.

c. Instrumented impact tests indicate that the embrittlement initially results in a loss of resistance to crack propagation rather than initiation.

d. J_I-R curve test results show that embrittlement causes unstable brittle fracture at peak load rather than the stable crack growth characteristic of as-welded samples. However, crack initiation resistance is only marginally reduced.

e. Overall, the results suggest that the embrittlement primarily causes a loss in crack tolerance in the weldment. They point to the need for care in using a single material parameter such as K_{Ic} to describe overall fracture properties.

ACKNOWLEDGEMENTS

Much of the Charpy impact work was conducted by B.F. Peters and his colleagues at DREP, and by Professor B. Hawbolt at the University of British Columbia, and their contributions are gratefully acknowledged. The J_I-R curve experiments were carried out in collaboration with J.P. Gough at DREP.

REFERENCES

1. Peters, B.F., "Charpy V-Notch Impact Studies on Stress Relieved HY130 Weldments", DREP Materials Report 79-G, December 1979.

2. Hawbolt, E.B., "Residual Stresses in Welded HY130 Steel", UBC Contract Report, July 1976.

3. Milliken, K.S. and Mitchell, C.M., "Comparison of Strain Gauge and X-Ray Diffraction Measurements of Residual Stresses in a Weldment of HY130 Steel", in Weldments, Physical Metallurgy and Failure Phenomena, Proceedings of the Fifth Bolton Landing Conference, edited by R.J. Christoffel, p. 83, 1979.

4. Dawes, M.G., "Fracture Initiation in Weld Metals: Effects of Heat Input, Welding Position, Thermal Stress Relief Treatment, and Dynamic Strain Ageing Embrittlement", Welding Institute Report E/33/70, January 1970.

5. Oleford, I., "Temper Embrittlement", International Metallurgical Reviews, Vol. 23, No. 4, p. 149, 1978.

6. Military Specification - Steel Plate, Alloys, Structural, High Yield Strength (HY130), MIL-S-24371A (SHIPS), August, 1975.

7. Shackleton, D.N., "Welding HY100 and HY130 Steels - A Literature Review", Welding Institute Report C287/3/72, September 1973.

8. Stahlkopk, K.E., Smith, R.E., Server, W.L., and Wullaert, R.A., "Preliminary Results of a Program for Developing Fracture Toughness Data on Ferritic Nuclear Pressure Vessel Steels", in Cracks and Fracture, STP 601, edited by J.L. Swedlow and M.L. Williams, ASTM, Philadelphia, p. 291, 1976.

9. Albrecht, Andrews, W.R. Gudas, J.P., Joyce, J.A., Loss, F.L., McCabe, D.E., Schmidt, D.W., and VanDerSluys, W.A., "Tentative Test Procedure for Determining the Plane Strain J_I-R Curve", Journal of Testing and Evaluation, Vol. 10, No. 6, P. 245, November 1982.

10. Ernst, H., Paris, P.C., and Landes, J.D., "Estimations of the J-Integral and the Tearing Modulus from a Single Specimen Test Record", in Fracture Mechanics: Thirteenth Conference, STP 743, edited by R. Roberts, ASTM, Philadelphia, p. 476, 1981.

11. Matthews, J.R., and West, G.D., "J_{Ic} Measurement Point Determination for HY130, CMS-9, and Inconel Alloy 718", Journal of Testing and Evaluation, Vol. 11, No. 3, p. 217, May 1983.

12. Joyce, J.A., and Vassilaro, M.G., "An Experimental Evaluation of Tearing Instability Using the Compact Specimen", in Fracture Mechanics: Thirteenth Conference, STP 743, edited by R. Roberts, ASTM, Philadelphia, p. 525, 1981.

DISTRIBUTION

Report No.	DREP Technical Memorandum 84-1
Title:	Fracture Of Temper Embrittled HY130 Weldments
Author:	J. Morrison
Dated:	February 1984
Security Grading:	Unclassified

3 - DSIS
Circulate to:
D/CRAD(L)
DST(OV)-2

1 - NDHQ Library for Micromedia Ltd.

1 - DGAEM
1 - DGLEM
1 - DGMEM
1 - DAS Eng-6
1 - DMES-4
1 - QETE

1 - DREA
1 - DREP
1 - DRES
1 - DREV

1 - RMC
1 - RRMC

1 - SRU(P)
1 - NEU(P)

UNCLASSIFIED UNLIMITED
Security Classification

DOCUMENT CONTROL DATA - R & D
(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATING ACTIVITY
Defence Research Establishment Pacific
FMO Victoria, BC
VOS 1BO

2a. DOCUMENT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. DOCUMENT TITLE
Fracture Of Temper Embrittled HY130 Weldments

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
DREP Technical Memo

5. AUTHOR(S) (Last name, first name, middle initial)
Morrison, J.

6. DOCUMENT DATE
February 1984

7a. TOTAL NO. OF PAGES
20

7b. NO. OF REFS
12

8a. PROJECT OR GRANT NO.
26B

9a. ORIGINATOR'S DOCUMENT NUMBER(S)
84-1

8b. CONTRACT NO.

9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)

10. DISTRIBUTION STATEMENT
Unlimited distribution.

11. SUPPLEMENTARY NOTES

12. SPONSORING ACTIVITY
DREP

13. ABSTRACT

This report describes an investigation of the embrittlement associated with thermal stress relief of multipass butt welds in 13-mm and 25-mm HY130 plate. While the parent metal is not greatly affected by a stress relief treatment, shielded metal-arc weldments suffer a drastic drop in Charpy V-notch toughness when slow cooled from the tempering temperature. Instrumented impact tests suggest that while both crack initiation and propagation resistance are lowered by slow cooling after tempering, the energy associated with propagation is more severely affected. J_I-R curve measurements tend to support these observations; the crack initiation toughness remains relatively high and the embrittlement is characterized by a loss of tolerance for propagating cracks.

DSIS
70-070

KEY WORDS

fracture
embrittlement
weldments
stress relief
toughness
crack tolerance

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the organization issuing the document.

2a. DOCUMENT SECURITY CLASSIFICATION: Enter the overall security classification of the document including special warning terms whenever applicable.

2b. GROUP: Enter security reclassification group number. The three groups are defined in Appendix 'M' of the DRB Security Regulations.

3. DOCUMENT TITLE: Enter the complete document title in all capital letters. Titles in all cases should be unclassified. If a sufficiently descriptive title cannot be selected without classification, show title classification with the usual one-capital-letter abbreviation in parentheses immediately following the title.

4. DESCRIPTIVE NOTES: Enter the category of document, e.g. technical report, technical note or technical letter. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the document. Enter last name, first name, middle initial. If military, show rank. The name of the principal author is an absolute minimum requirement.

6. DOCUMENT DATE: Enter the date (month, year) of Establishment approval for publication of the document.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the document.

8a. PROJECT OR GRANT NUMBER: If appropriate, enter the applicable research and development project or grant number under which the document was written.

8b. CONTRACT NUMBER: If appropriate, enter the applicable number under which the document was written.

9a. ORIGINATOR'S DOCUMENT NUMBER(S): Enter the official document number by which the document will be identified and controlled by the originating activity. This number must be unique to this document.

9b. OTHER DOCUMENT NUMBER(S): If the document has been assigned any other document numbers (either by the originator or by the sponsor), also enter this number(s).

10. DISTRIBUTION STATEMENT: Enter any limitations on further dissemination of the document, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this document from their defence documentation center."

(2) "Announcement and dissemination of this document is not authorized without prior approval from originating activity."

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document, even though it may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall end with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (TS), (S), (C), (R), or (U).

The length of the abstract should be limited to 20 single-spaced standard typewritten lines; 7½ inches long.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a document and could be helpful in cataloging the document. Key words should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context.